U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TCREC TECHNICAL REPORT 62-47

GROUND OPERATIONAL RECOVERY TESTS OF THE LW-1 EJECTION SEAT

Task 9R38-01-017-61

Contract DA 44-177-TC-659

June 1962

prepared by:

NORTH AMERICAN AVIATION, INC.
Columbus, Ohio

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HEADQUARTERS
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

The work described in this report was accomplished by North American Aviation, Inc. for the U. S. Army Transportation Research Command. The report has been reviewed by this Command and is considered to be technically sound. The report is published for the exchange of information and stimulation of ideas.

It should be noted that the only tests conducted to date have been at zero velocity. Plans for sled tests are now being formulated.

FOR THE COMMANDER:

Kenneth B. Abel
KENNETH B. ABEL
Captain TC
Adjutant

APPROVED BY:

S. Blair Poteate, Jr.
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Project Engineer

Contract DA-44-177-TC-659
June 1962

GROUND OPERATIONAL RECOVERY TESTS OF THE LW-1 EJECTION SEAT

TCREC 62-47
(North American No. NA 60H-667)

Prepared by:
North American Aviation, Inc.
Columbus, Ohio

for
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

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SUMMARY

The LW-1 Escape System Program consisted of two static development firings and four static demonstration firings. The development firings were required to define the lateral rocket thrust moment arm and to perfect the separation latch assembly. The demonstration firings proved the system's recovery capabilities under zero attitude, zero speed conditions. Analytical substantiation of recovery at velocities up to 300 knots is presented. Catapult acceleration forces are less than 12 G's with rates of onset of acceleration less than 250 G's/second.

Maximum sink rate and angle of dive recovery capabilities are achieved by the immediate ballistic deployment of the personnel parachute. Design simplicity minimizes maintenance requirements. Design simplicity and redundant gas systems optimize reliability.

CONCLUSIONS

The LW-1 Escape System will recover an airman without injury or incapacitation from any point of the envelope shown in Figure 9. Maximum angle-of-dive recovery capabilities are realized by the immediate, ballistic deployment of the recovery parachute. Reliability exceeds that of all other escape systems due to design simplicity and parallel gas systems to the catapult rocket. Design simplicity also results in absolute minimum maintenance requirements.

INTRODUCTION

The North American Aviation, Columbus Division, LW-1 Escape System was developed to meet the needs of flight crewmen of experimental VTOL, STOL, and flying platform type U. S. Army vehicles. It is a lightweight system which provides recovery at 0 - 300 KEAS "on the deck" and up to 10,000 feet altitude. Higher altitude recovery is provided at reduced equivalent air speeds.

Simplicity, low cost, and ease of maintenance are other factors that influenced the design of the LW-1 seat. Included in the construction of this seat are components developed and qualified over the past five years for the T2J-1 subsonic, and A3J-1 supersonic crew escape systems. Also, invaluable experience gained on those programs relative to seat dynamics, ballistic and mechanical components, restraint, and recovery led to the development of the LW-1 System with a minimum of developmental testing.

In response to NAA Report No. NA 60H-55, "Proposal for Lightweight (LW-1) Escape System for Experimental Flying Vehicles for the U. S. Army Transportation Research Command," dated 25 January 1960 and revised 16 May 1960, Contract DA44-177-TC-659 was awarded to the Columbus Division in June 1960.

This report presents a brief description of system operation, performance characteristics, and results of testing conducted under the aforementioned contract.

SYSTEM DESCRIPTION

The LW-1 Escape System shown in Figure 1 is completely automatic upon initiation. Ejection is effected by one-motion actuation of the "D" ring located on the front of the seat bucket as shown in Figure 2. A dual initiation system consisting of two independently fired T-30 initiators ports gas into the top of the unit. Immediately upon ignition of the catapult phase of the catapult-rocket the seat moves up the bulkhead and the drogue gun striker arm, as shown in Figure 3, contacts the striker located on the top bulkhead fitting, fires the drogue gun.

The drogue gun slug pulls the ripcord which opens the parachute pack and starts deployment as shown in Figure 4. The lower portion of the pack is partially closed by a flap suspended by breakcords to prevent the main canopy skirt from dropping below the seat due to ejection accelerations. As the drogue gun slug moves further away from the seat, this lower flap is opened and the canopy is fully stretched.

As the drag loads build up in the parachute, the risers become free of the seat and the separation lanyard actuates the separation latch mechanism as shown in Figures 5 and 6. The bucket and carriage assembly then separates from the back assembly which the airman retains with his harness. This is shown in Figures 7 and 8.

A manual parachute ripcord is provided in the conventional location on the left shoulder of the airman. In the event of complete system failure after clearing the cockpit, the manual handle may be pulled, releasing a conventional type of spring-loaded pilot chute into the windstream and recovery is accomplished in the normal manner.

PERFORMANCE CHARACTERISTICS

The 28-foot standard flat type parachute canopy is the primary recovery device on the LW-1 seat. This canopy has been used by the Services for many years, mainly as an escape parachute. It has been used successfully in the speed range of zero to 300 knots EAS at altitudes of zero to 10,000 feet. Minor fabric damage may occur at the most extreme conditions, but the rate of descent will not be appreciably affected. The allowable opening velocity of the parachute as predicted from opening shock data is shown on Figure 9. This curve represents the predicted operational envelope of the LW-1 Seat.

The Rocket Thrust Moment Arm (distance between total CG and rocket thrust line) affects initial seat stability. A "plus" moment arm causes the seat to pitch head aft at a rate depending on the magnitude of the moment arm. The moment arm for a given range of man sizes is established by the angle and location of the rocket nozzle.

The LW-1 seat has a plus moment arm so that the seat pitches head aft at a controlled rate during rocket burning. The head aft pitch rate is greater for a small man than for a large man because of their difference in moment of inertia. The LW-1 seat also has a lateral rocket thrust moment arm so that a small amount of roll and yaw is produced.

At zero and low ejection speeds, the rocket (with a given moment arm) controls seat stability. The parachute is deployed prior to seat separation from the rails so that line stretch occurs before seat pitch becomes excessive. The small amount of roll and yaw resulting from the lateral rocket thrust moment arm aids in separating the deploying parachute from the seat. The parachute then limits seat pitch and separates the man from the carriage portion of the seat.

At higher speeds, aerodynamic forces have an effect on seat stability. The term "tip-off" is used to define the head aft seat pitch resulting from aerodynamic forces acting on the upper portion of the seat prior to separation from the rails.

At higher speeds, the seat pitches head aft at a greater rate due to the combined effects of tip-off and rocket thrust moment arm. In opposition to this, the parachute deploys faster so that seat pitch is again limited to an acceptable range.

Maximum seat pitch angles occur at zero speed and it should be noted that parachute effectiveness in limiting seat pitch was sufficiently demonstrated at this condition in these static ejections.

Figure 10 presents predicted seat pitch angles versus time from ejection and the maximum pitch angles are indicated for zero speed and 300 KEAS.

Figure 11 presents predicted typical trajectories for various speeds of the LW-1 seat. It should be noted that the length of trajectory is relatively short in all cases. This is made possible by immediate

deployment of the parachute at all speeds so that inflation occurs prior to reaching the peak of trajectory thus providing seat stability and a wide margin of recovery.

An outstanding feature of the LW-1 System is its excellent angle-of-dive recovery capability. This is also made possible by the shortness of trajectory length. Figure 12 presents a predicted comparison of LW-1 angle-of-dive capability to that of another ejection seat currently used in Army aircraft.

STATIC STRUCTURAL TESTS

Structural tests of the LW-1 seat were conducted with results as follows:

The seat structure, with the seat rails inclined 13° aft of vertical, was subjected to an ultimate load of 5,760 pounds. Ultimate load is defined as 150 percent of design limit load and is computed by multiplying the ejection design limit load of 3,840 pounds by a factor of 1.5.

For the static ejection condition a dummy rocket supported the seat in a partial-fired position. The test loads were applied to the seat by two hydraulic jacks. The jacks were attached to a steel beam positioned on wooden blocks that distributed the load to the seat bottom as shown in Figures 13 and 14. Deflections of the lower end of each rail were recorded for each 20 percent of design limit load up to 115 percent design limit load.

To simulate crash conditions, a 20-G ultimate load was also applied by supporting the seat with a dummy rocket in a bottomed position. The test loads were applied by hydraulic jacks to the lap belt and to the shoulder harness fittings as shown in Figure 15. The lap belt was fastened around a steel contour fitting that was attached to the loading jack. The lap belt load of 2,070 pounds ultimate per side, pulled in the aft corners of the seat causing the corners to crack, however, the seat did support the ultimate load of 5,760 pounds through the two lap belt attachments and shoulder harness attachment as shown in Figures 16 and 17.

INERTIA STUDY

A trifilar pendulum was set up in the Dynamics Laboratory to determine moments of inertia in three planes with live subjects, represent-

ing five and 95 percentile configurations, placed in the seat. Periods of oscillation were measured and moments of inertia in pitch, roll and yaw were calculated for use in actual ejection tests and for predicting dynamic characteristics.

Results of the inertia study are as follows:

Condition	Wt of Seat	Wt of Man & Equipment	Total Weight Man and Seat
95 percentile	71.9 lbs	193.9 lbs	265.8 lbs
5 percentile	71.9 lbs	166.2 lbs	238.1 lbs

Condition	Roll	Pitch	Yaw
95 percentile	53,246 lb-in^2	61,051 lb-in^2	29,555 lb-in^2
5 percentile	40,379 lb-in^2	49,498 lb-in^2	23,648 lb-in^2

Upon completion of the tests with the seat and live subjects, a steel bar with a known moment of inertia was placed on the pendulum. The period of the steel bar was measured and moment of inertia determined using the trifilar set-up. A comparison in moments of inertia between the known value and experimental value showed the experimental value to be 1.3 percent below the known value. From these tests it may be assumed the seat values obtained are within ± 2 percent of actual values.

STATIC TEST FIRINGS

Figures 18, 19, 20, and 21 show the static test rig with seat installed. This test set-up was used throughout the conducting of four static firings at the North American Aviation, Columbus Facility. Figure 22 presents tabulated criteria and pertinent results of each test. All components tested were of production configuration except the XM-13 catapult rocket. The catapult rockets used in these tests produced excessive accelerations and rates of onset of accelerations. Production units will produce a peak acceleration of 12 G's with rates of onset of acceleration less than 250 G's/sec.

TEST No. 1

Earlier testing of the LW-1 seat indicated that directing the rocket thrust centerline to one side of the ejected mass CG would (1) expand

the recovery envelope, (2) reduce the possibility of the airman touching down in the wreckage of his airplane following a low level ejection and (3) provide improved separation of the deploying parachute from the seat. This would be accomplished by the seat rolling and yawing at a controlled rate, resulting in a trajectory curving to one side of the initial seat heading.

Based on this knowledge, the first test was conducted using a 0.6-inch lateral rocket thrust moment arm. The resulting roll and yaw proved excessive and recovery was not accomplished. Figures 23 and 24 show the seat trajectory.

TEST No. 2

To further investigate seat yaw and roll, the second firing was conducted with a zero lateral rocket thrust moment arm. Also the pitch moment arm was increased to 1.6 inches which is a high extreme value for a 95 percentile man in the LW-1 seat. The seat rolled and yawed at an acceptable rate. Recovery was excellent with the dummy being approximately 76 feet above the ground at full parachute inflation. Figures 25 and 26 show the resulting trajectory. Separation of the parachute and dummy at the peak of the trajectory is not shown on Figure 25 due to the camera location. Corresponding figures for Test Numbers 3 and 4 show that this separation is adequate so that collision does not occur and tension is maintained in the parachute suspension lines.

TEST No. 3

Another extreme pitch moment arm of 2.0 inches was used on this test with a five percentile dummy. Similar roll and yaw characteristics to the preceding test were observed with the seat pitching head aft at an acceptable rate. Recovery was accomplished with the dummy approximately 73 feet above the ground at full parachute inflation.

The separation latch assembly which is actuated by force in the parachute risers and which allows separation of the carriage and bucket assembly from the back assembly, did not release due to limited freedom of rotation. A minor design change was made which consisted of further machining the latch mechanism so that it may be actuated throughout any angle of parachute pull.

Figures 27 and 28 present trajectory data.

TEST No. 4

To investigate ejection angles other than 13^{o} used on previous tests, the seat ejection angle was changed to 0^{o} as shown in Figure 29. A moderate pitch moment arm of 1.2 inches was used on this firing. Again, the lateral moment arm was zero and the seat dynamics were as predicted. Seat roll and yaw as well as head aft pitch were within acceptable limits. Recovery characteristics were excellent with the dummy approximately 132 feet above ground level at full parachute inflation. At this point the seat dynamics, hardware, and recovery characteristics were considered fully demonstrated and suitable for U. S. Army use. This test was also considered adequate demonstration of the design change made as a result of non-separation during the preceding test. Figures 30 and 31 present trajectory data.

TEST No. 5

For this test, conducted at ACEL, the center of gravity of the ejected mass was located 1.35 inches above the center line of rocket thrust. The end configuration was an armless dummy with a 24-pound telemetering package in the chest cavity. A total of eight pounds was added equally between both ankle areas to get a total ejected weight of 240.25 pounds. Drogue gun, catapult-rocket, parachute deployment, and seat/man separation functioned normally. Full parachute inflation was estimated at 60 feet.

TEST No. 6

This was the second test to be conducted at ACEL. The center of gravity of the ejected mass of 315 pounds was located 1.47 inches above the centerline of rocket thrust. Seat/man trajectory peak was approximately 135 feet with full parachute inflation estimated at 80 feet.

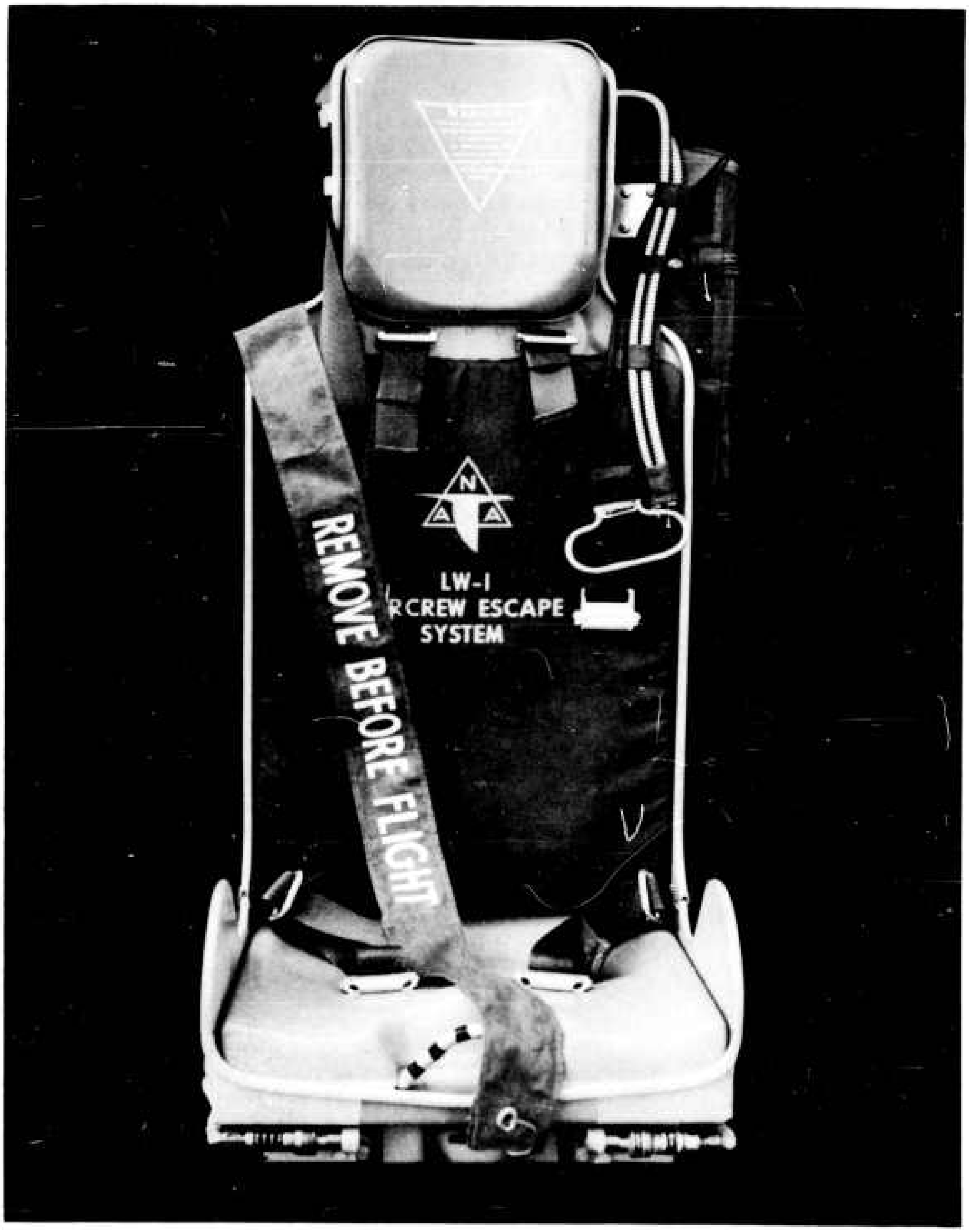

Figure 1. Photo LW-1.

Figure 2. Photo LW-1.

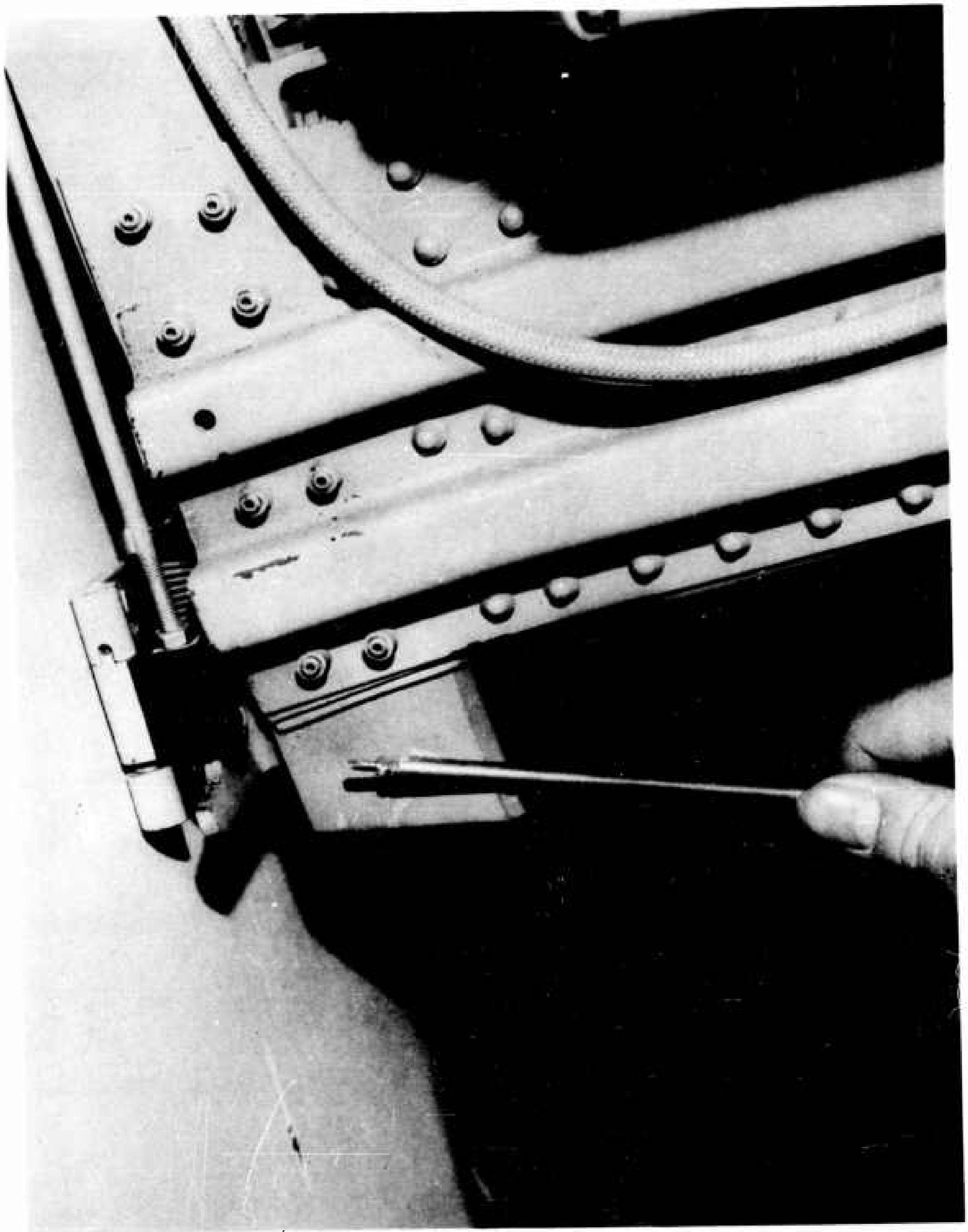

Figure 3. Photo LW-1.

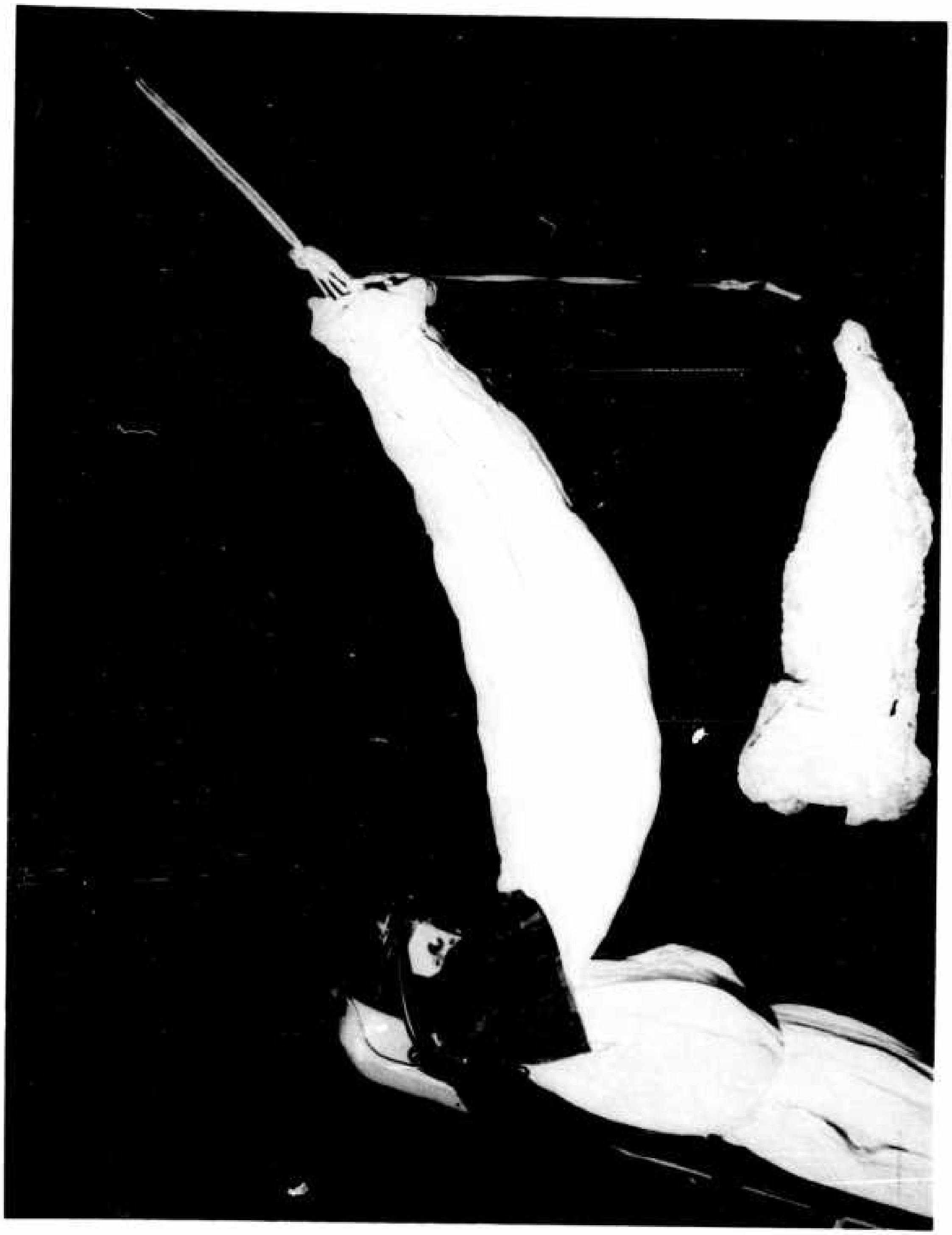

Figure 4. Photo LW-1.

Figure 5. Photo LW-1.

Figure 6. Photo LW-1.

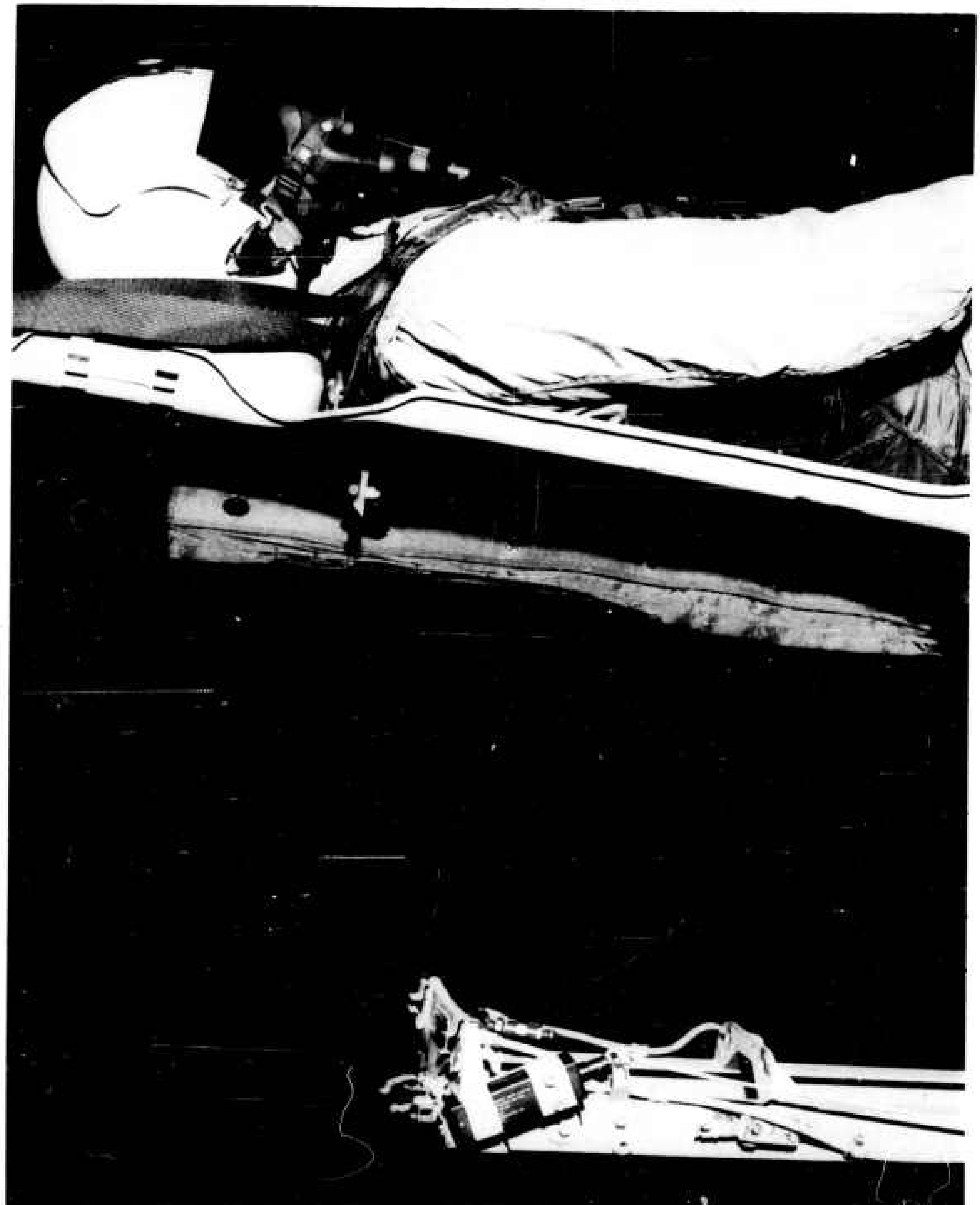

Figure 7. Photo LW-1.

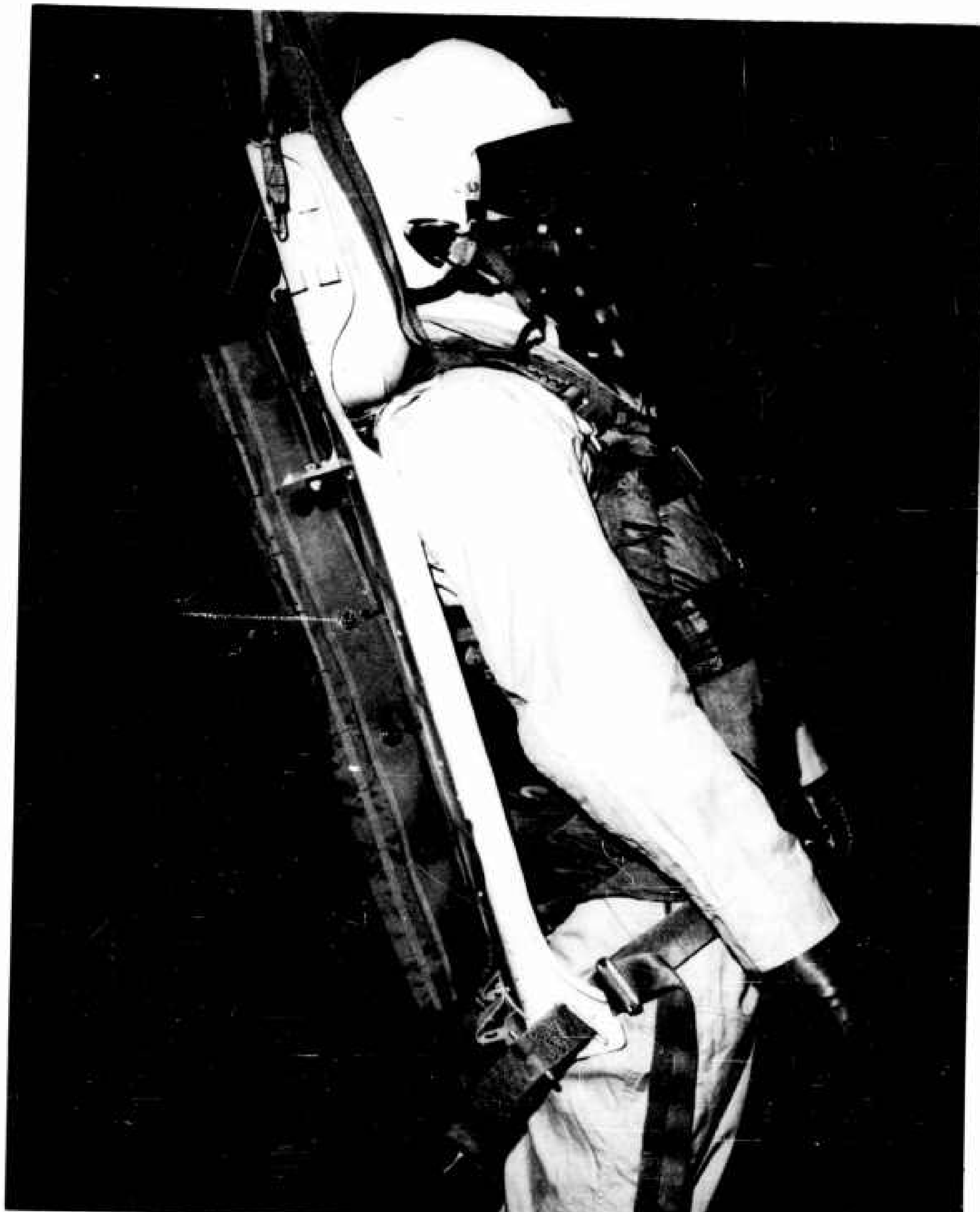

Figure 8. Photo LW-1.

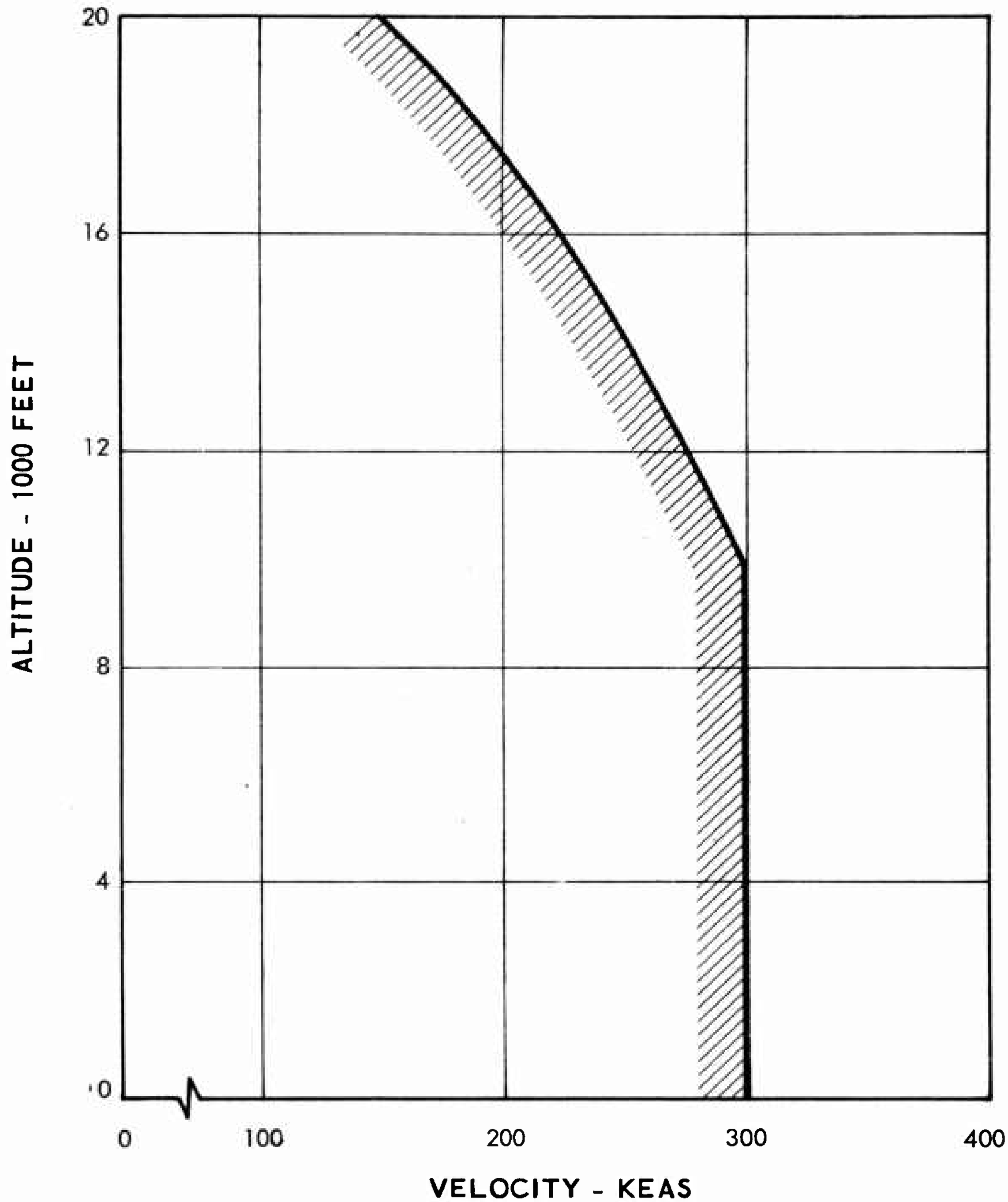

Figure 9. Graph - Allowable Parachute Velocity.

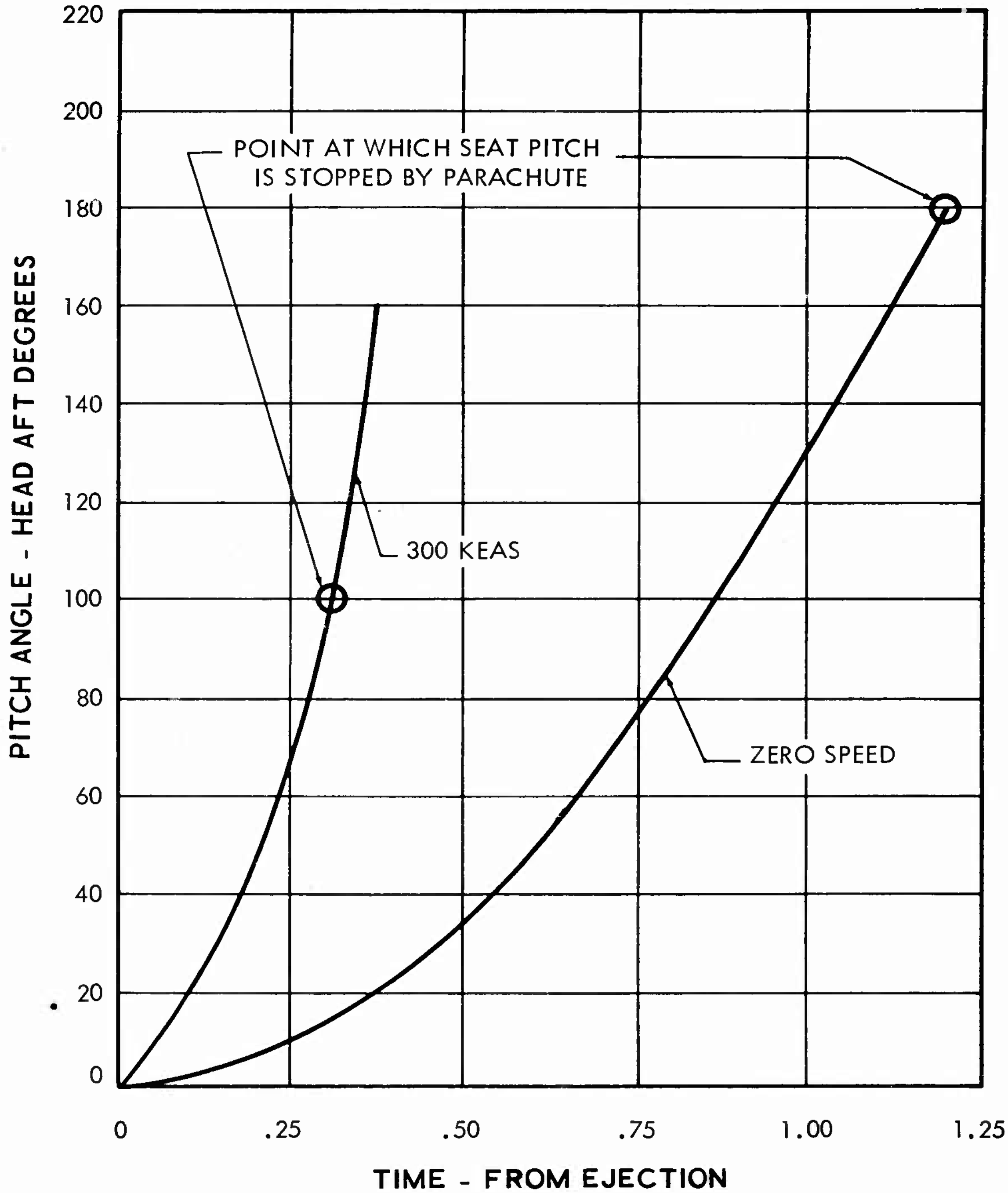

Figure 10. Graph - Maximum Pitch Angles.

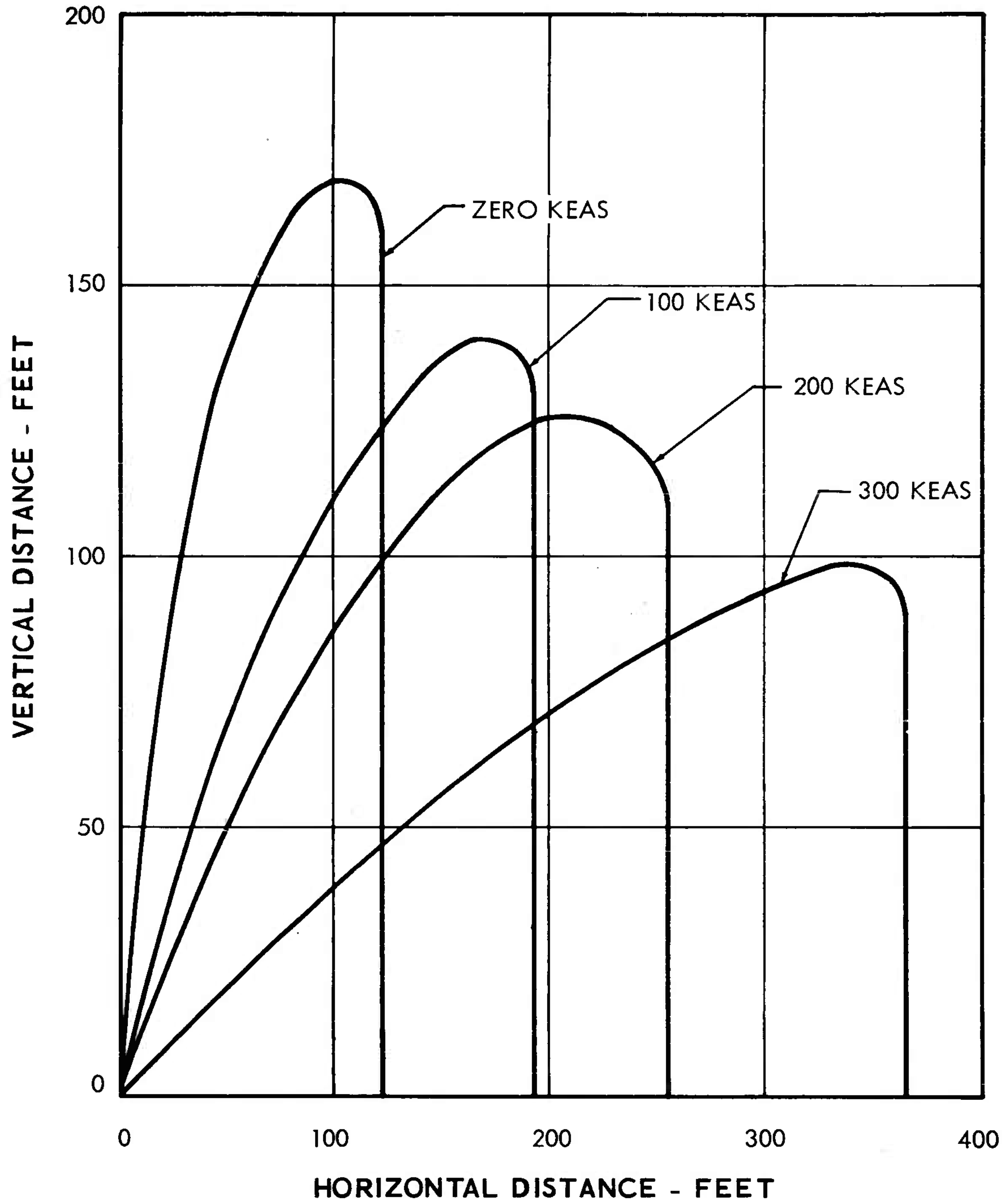

Figure 11. Trajectories.

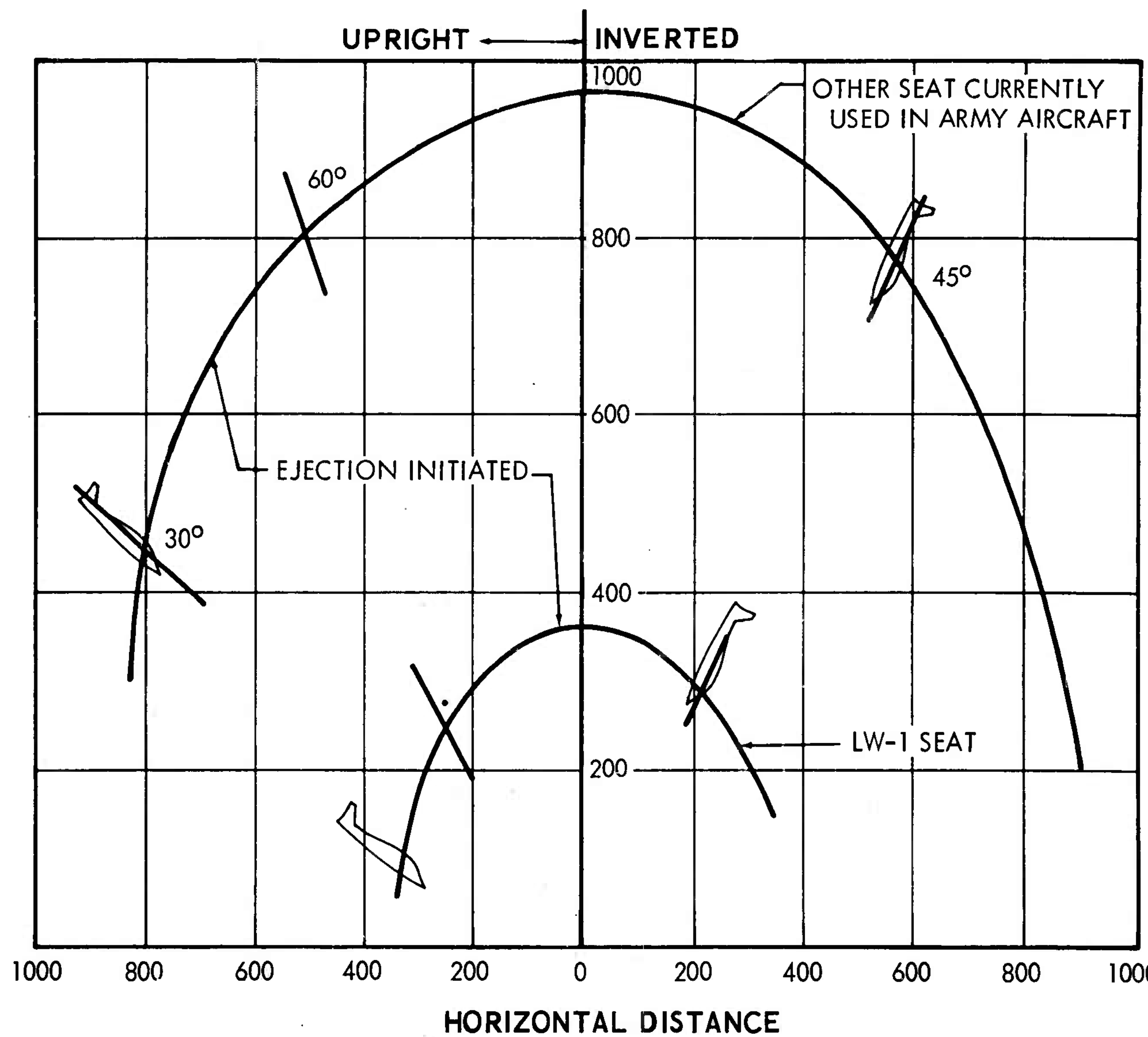

Figure 12. Angle-of-Dive Capabilities.

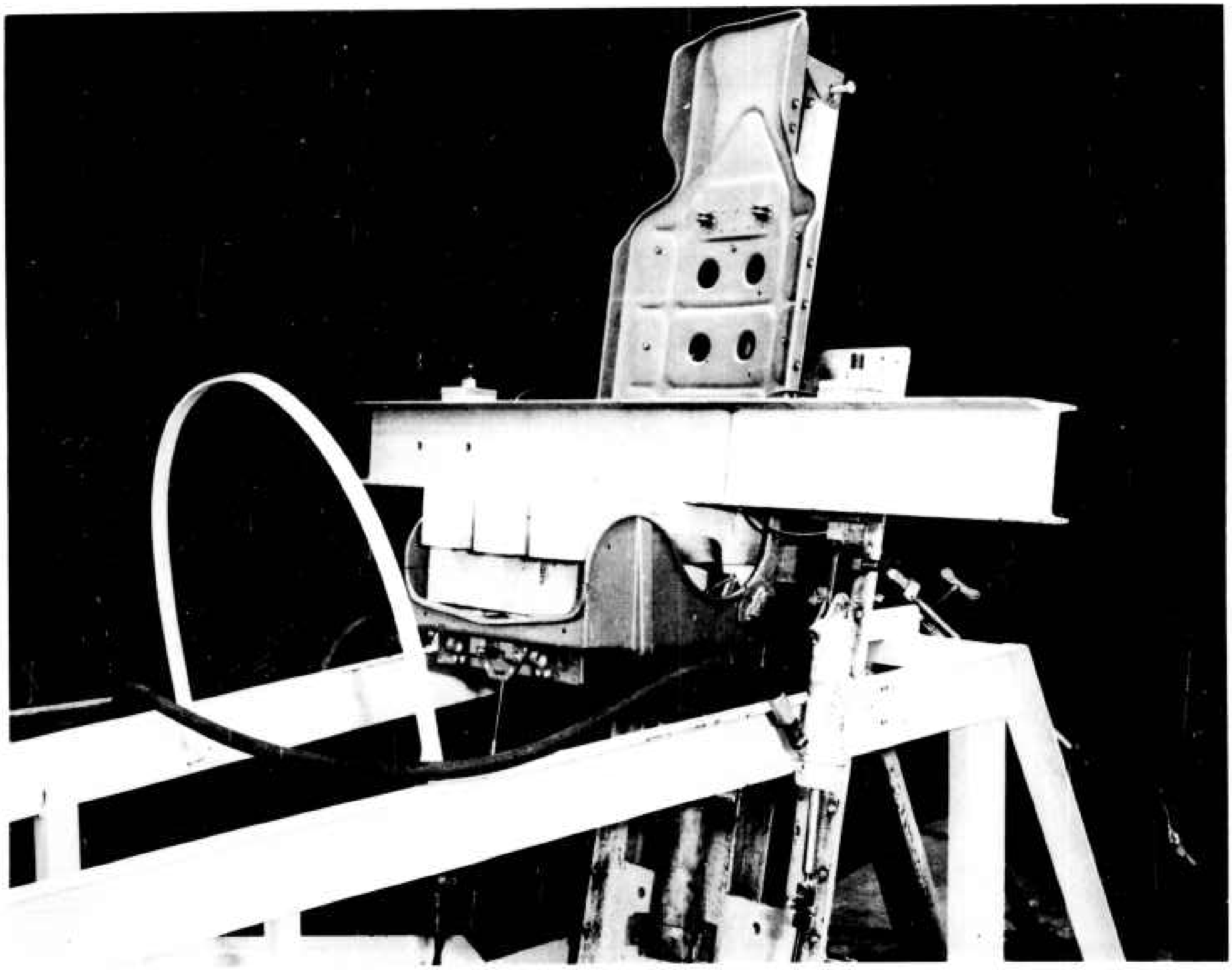

Figure 13. Photo - Structural Tests.

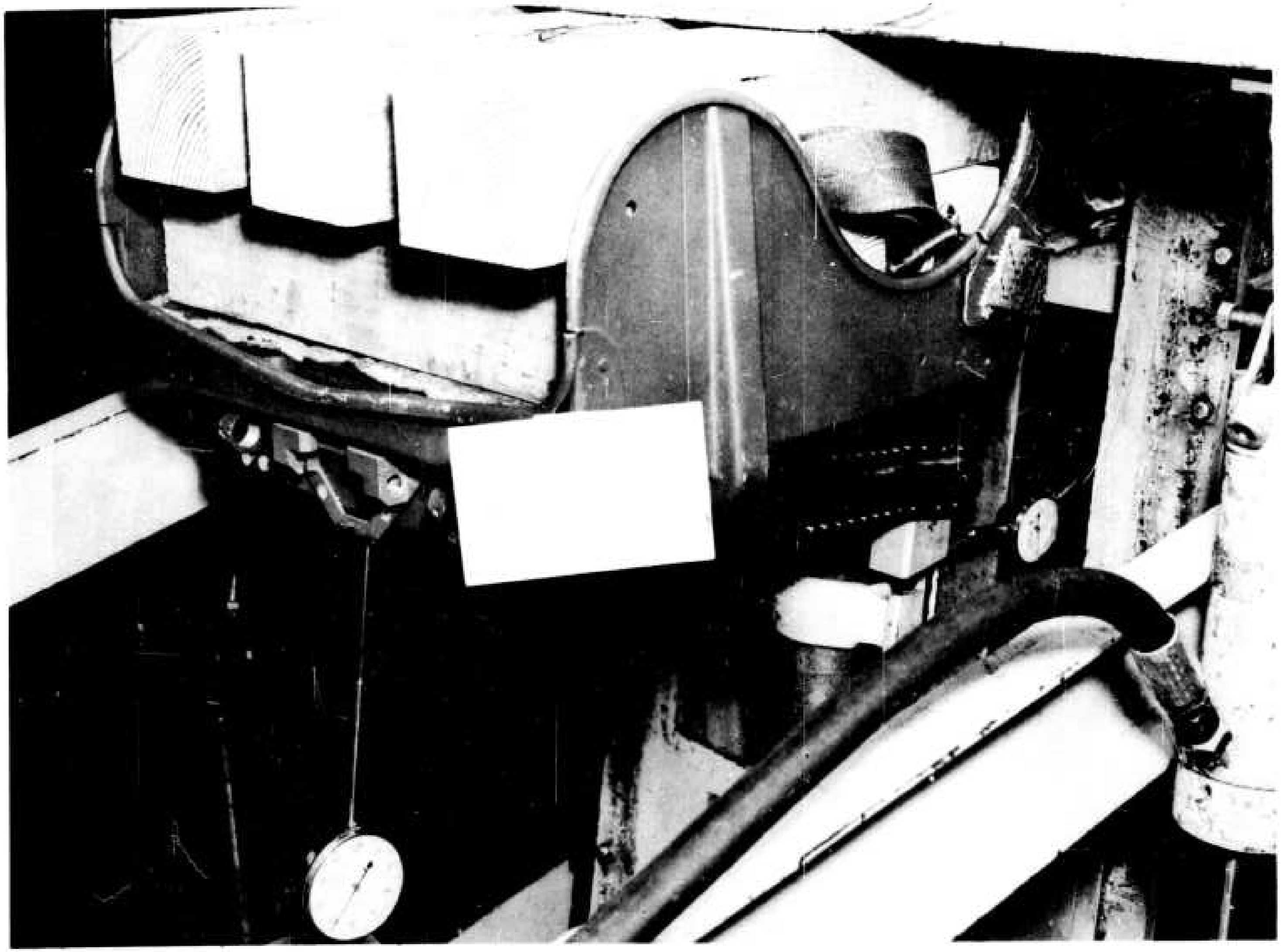

Figure 14. Photo - Structural Tests.

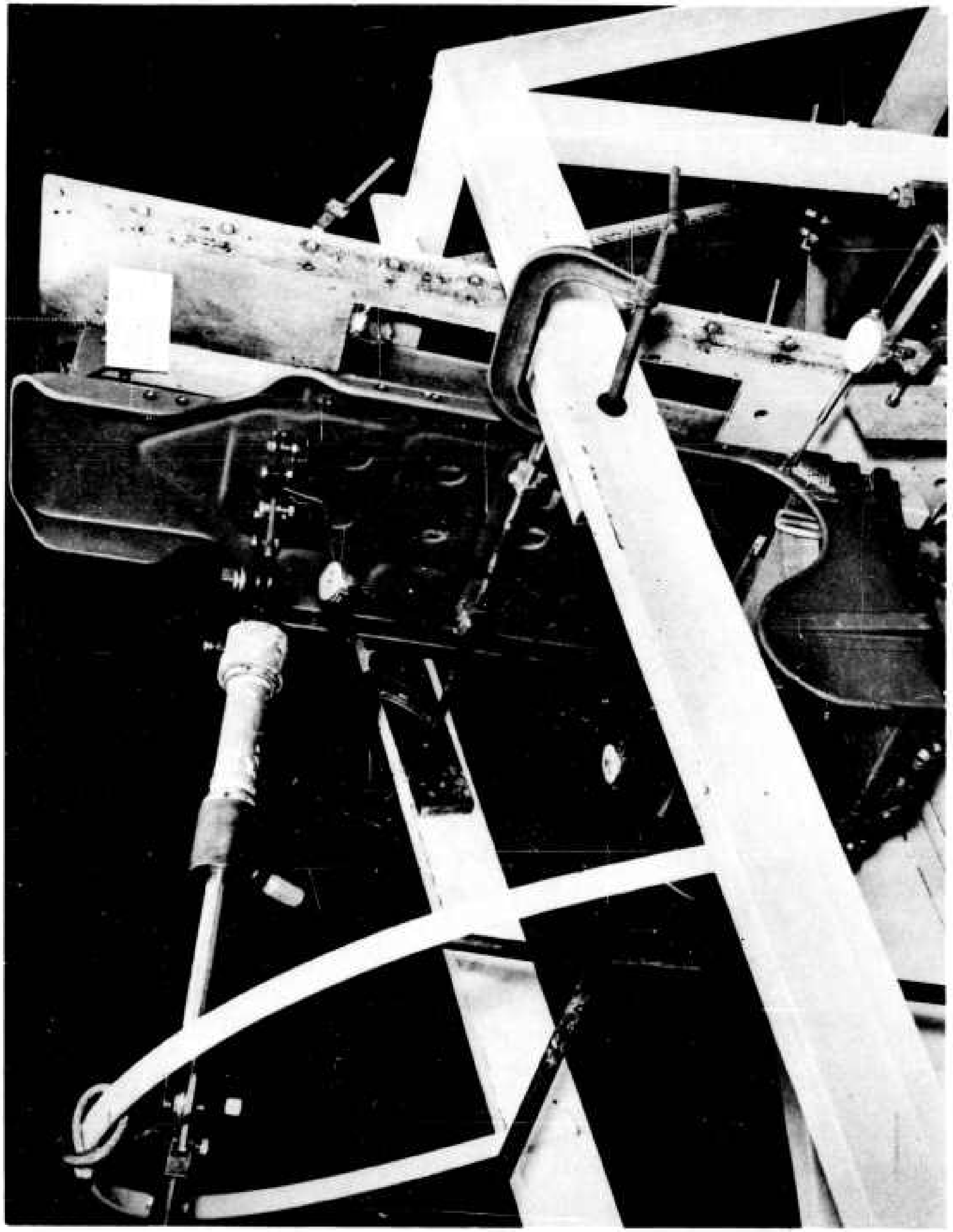

Figure 15. Photo - Structural Tests.

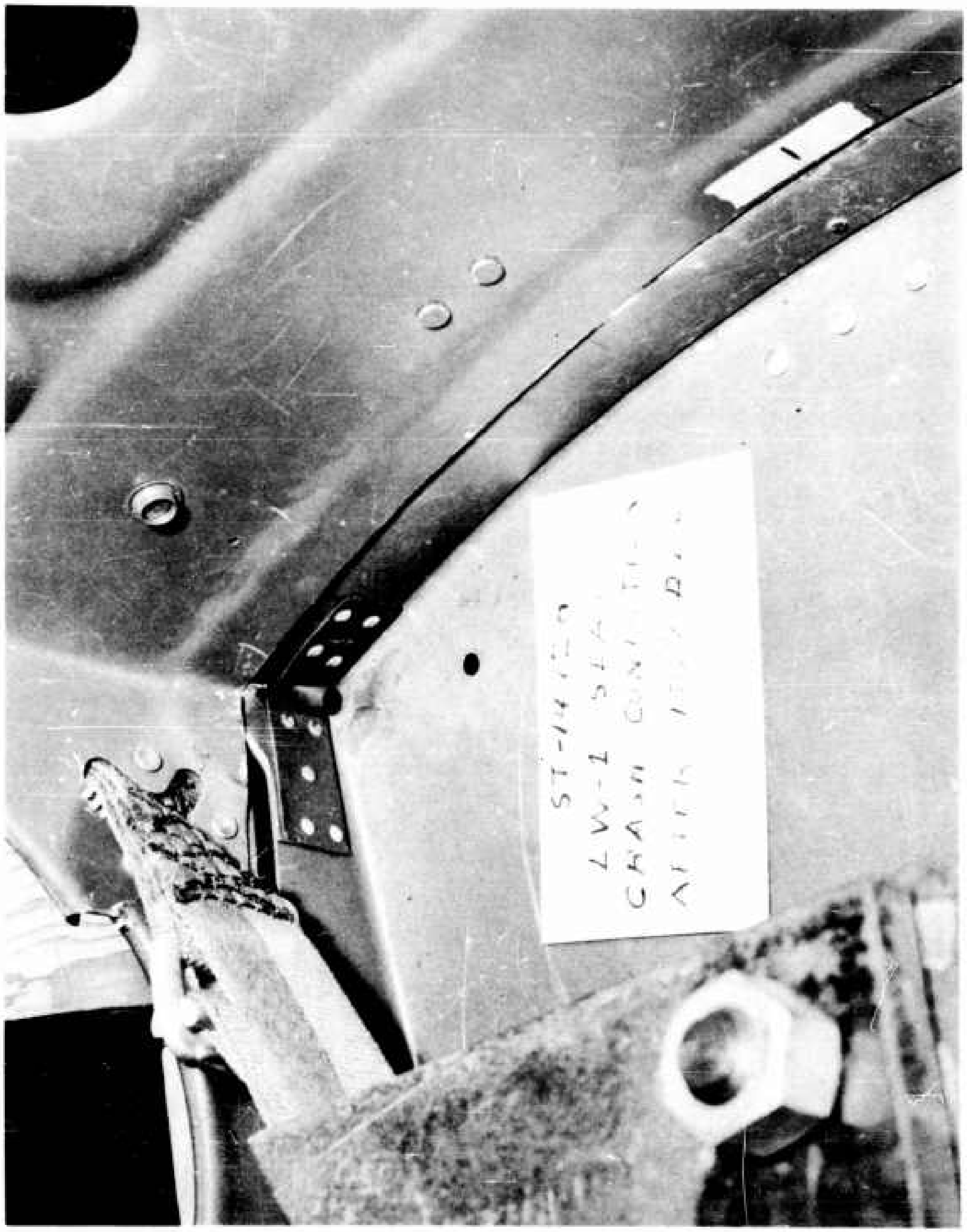

Figure 16. Photo - Structural Tests.

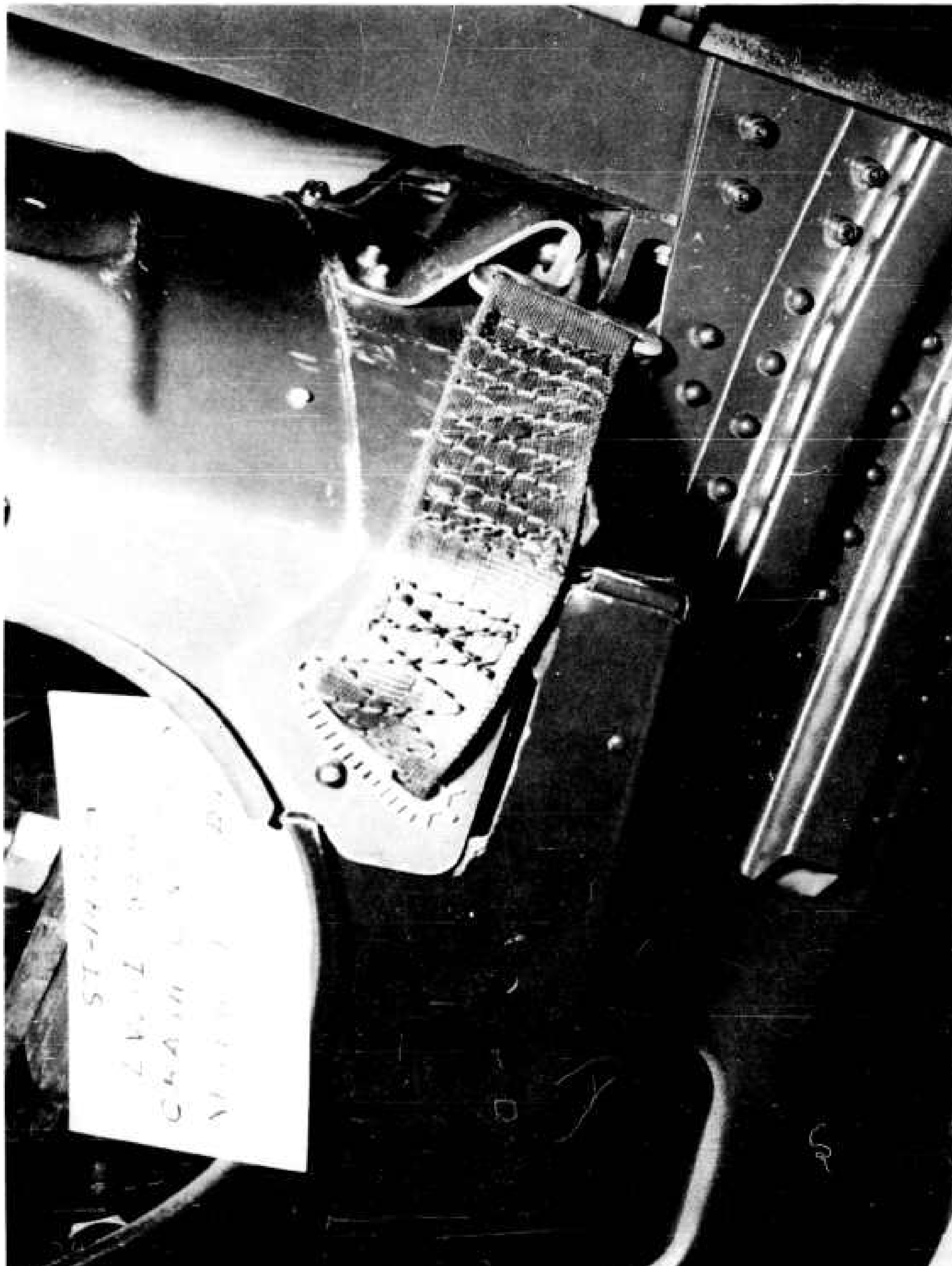

Figure 17. Photo - Structural Tests.

Figure 18. Photo - Static Ejection.

Figure 19. Photo - Static Ejection.

Figure 20. Photo - Static Ejection.

Figure 21. Photo - Static Ejection.

RESULTS OF LW-1 STATIC EJECTIONS						
Test Number	1	2	3	4	5	6
Date	9-28-60	9-29-60	10-3-60	10-5-60	1-10-62	1-20-62
Dummy Size - Percentile	5.0	95.0	5.0	5.0	5.0	95.0
Ejected Weight - Lbs	237.5	312.7	245.4	236.1	240.25	315.0
Actual Lateral Moment Arm - In.	0.6	0.	0.	0.	0.	0.
Actual Pitch Moment Arm - In.	0.9	1.6	2.0	1.2	1.35	1.47
Ejection Rail Angle - Degrees	13.0	13.0	13.0	0.	13.0	13.0
Peak Trajectory - Ft	74.0	114.0	122.0	164.0	100.0	135.0
Alt of Recovery - Ft	--	76.0	73.0	132.0	60.0	80.0

Figure 22. Results - Tabulated.

Figure 23. Photo - Test No. 1.

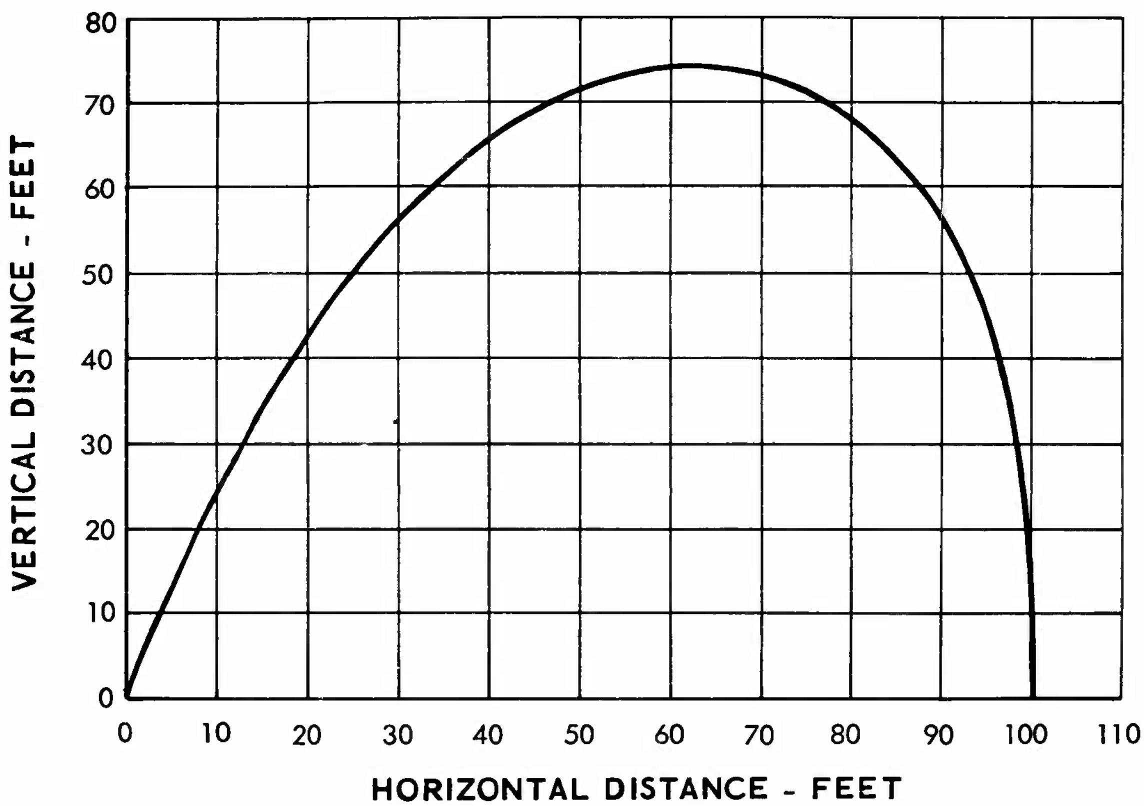

Figure 24. Trajectory - Test No. 1

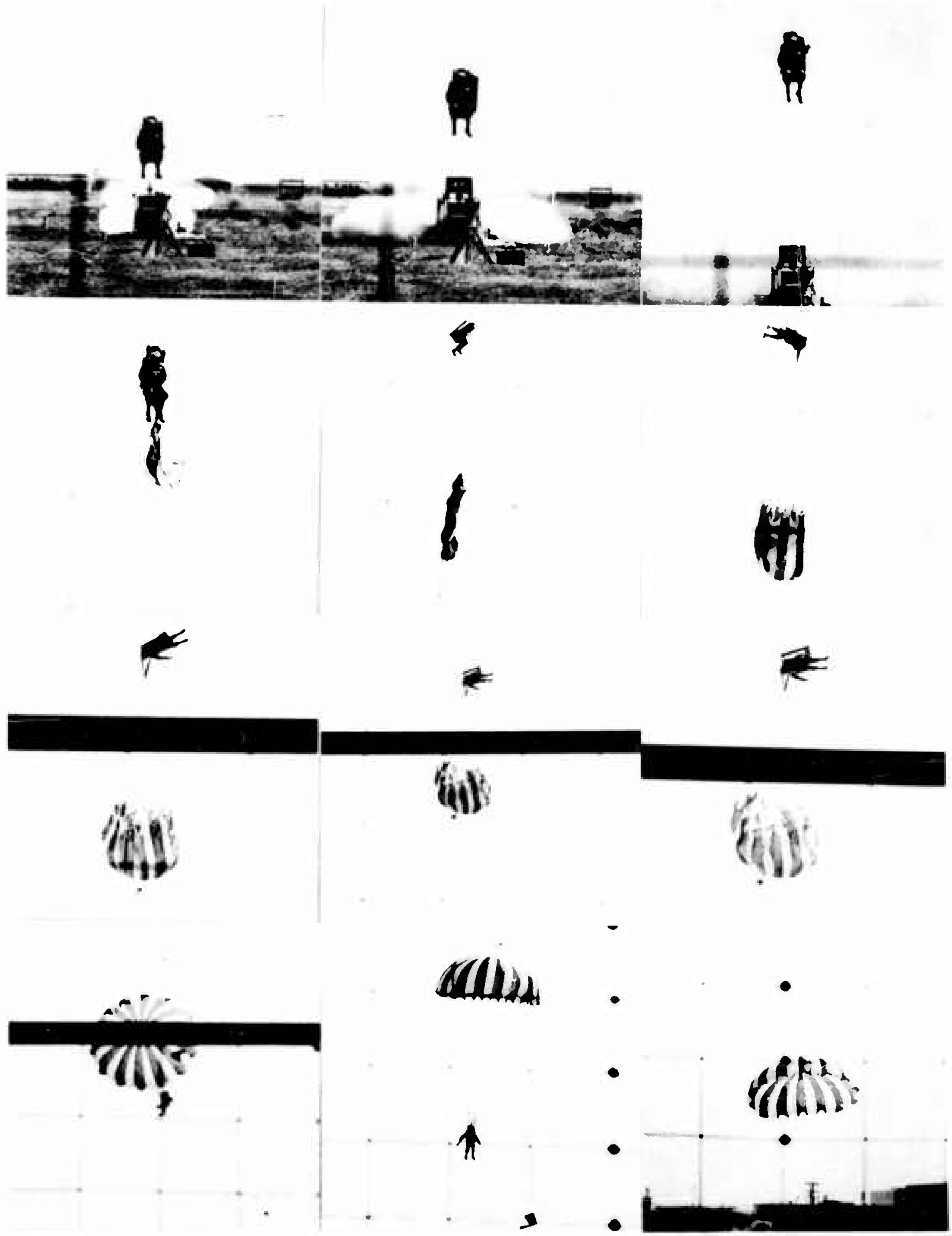

Figure 25. Photo - Test No. 2.

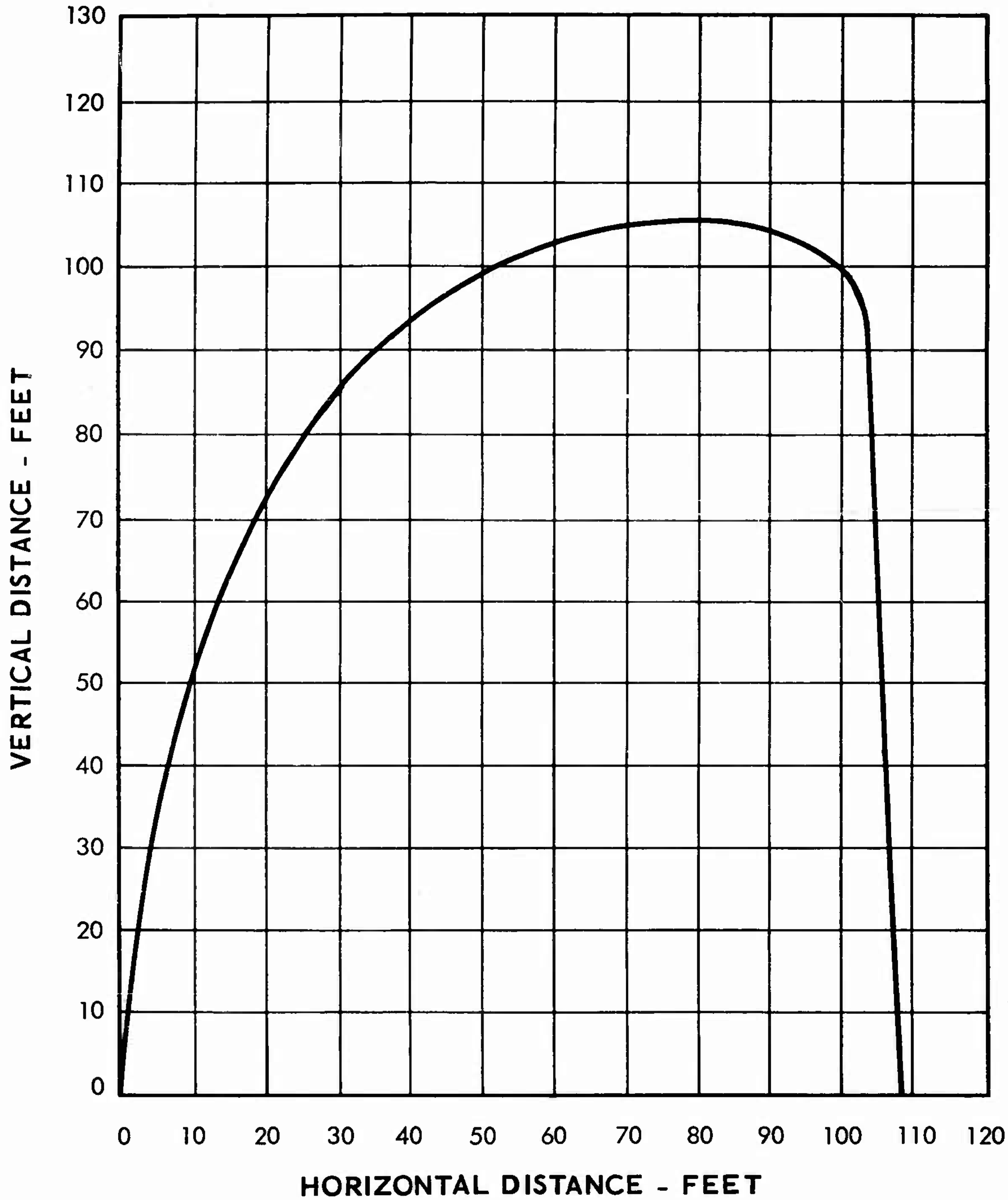

Figure 26. Trajectory - Test No. 2.

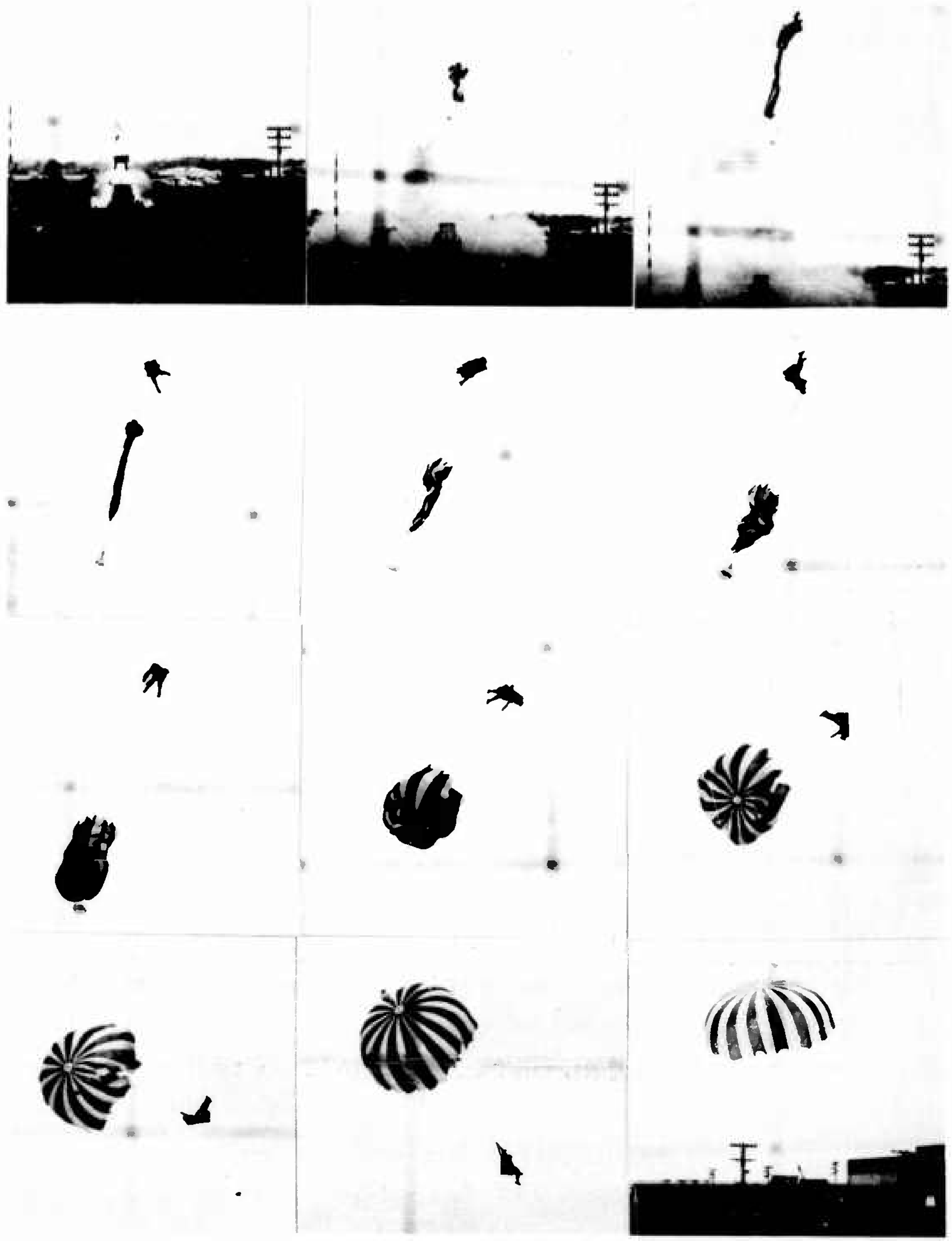

Figure 27. Photo - Test No. 3.

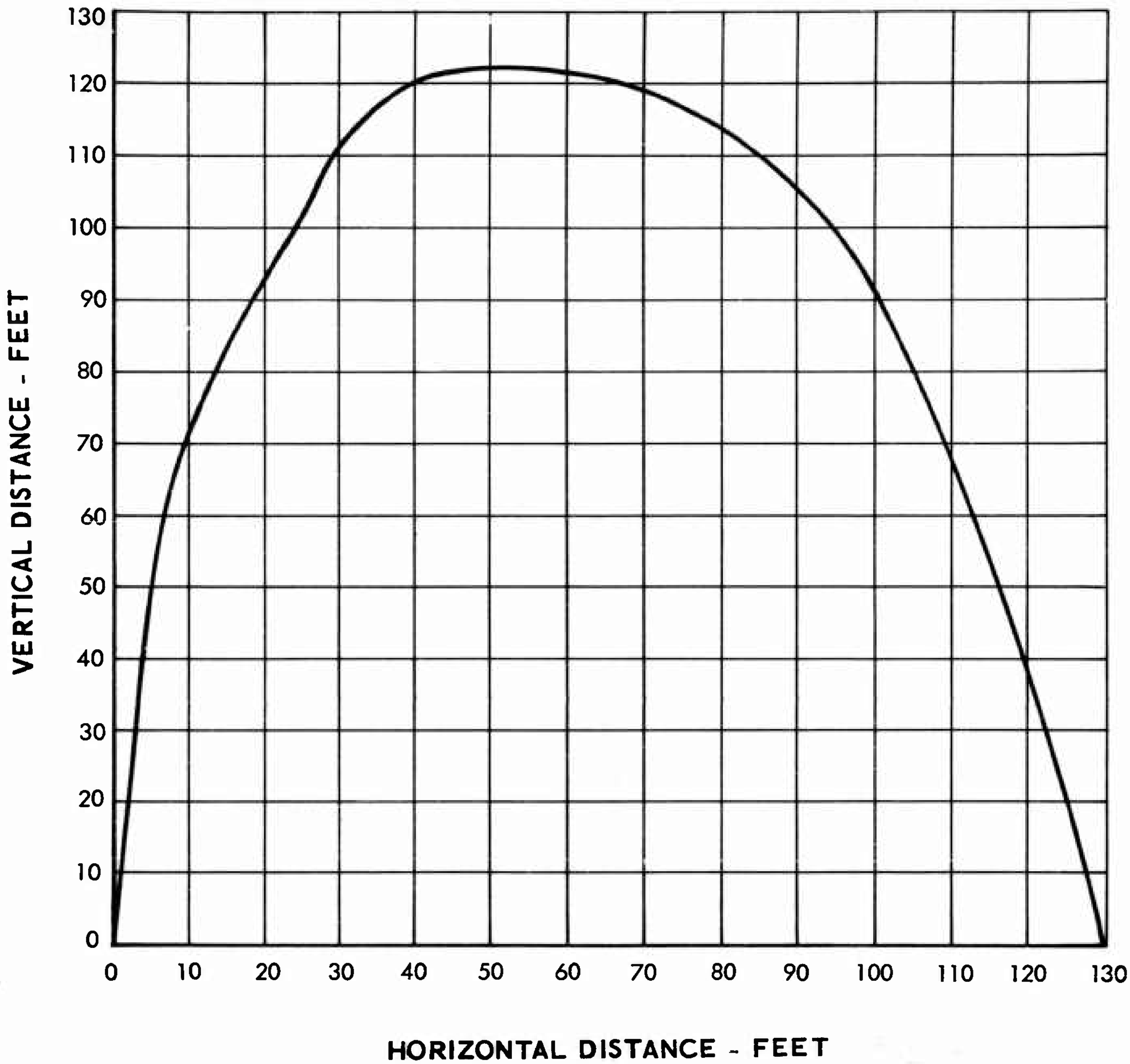

Figure 28. Trajectory - Test No. 3.

Figure 29. Photo - Static Ejection.

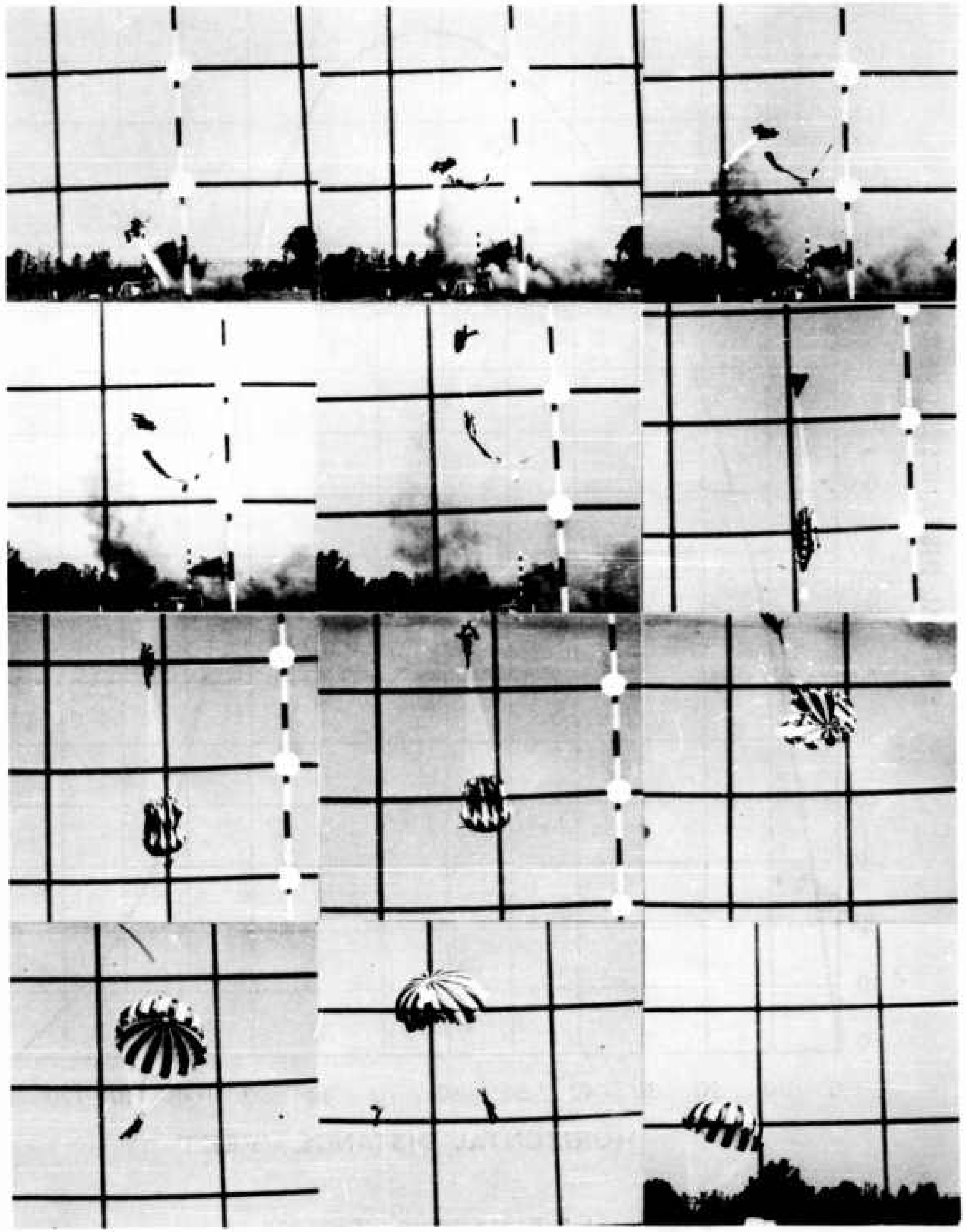

Figure 30. Photo - Test No. 4.

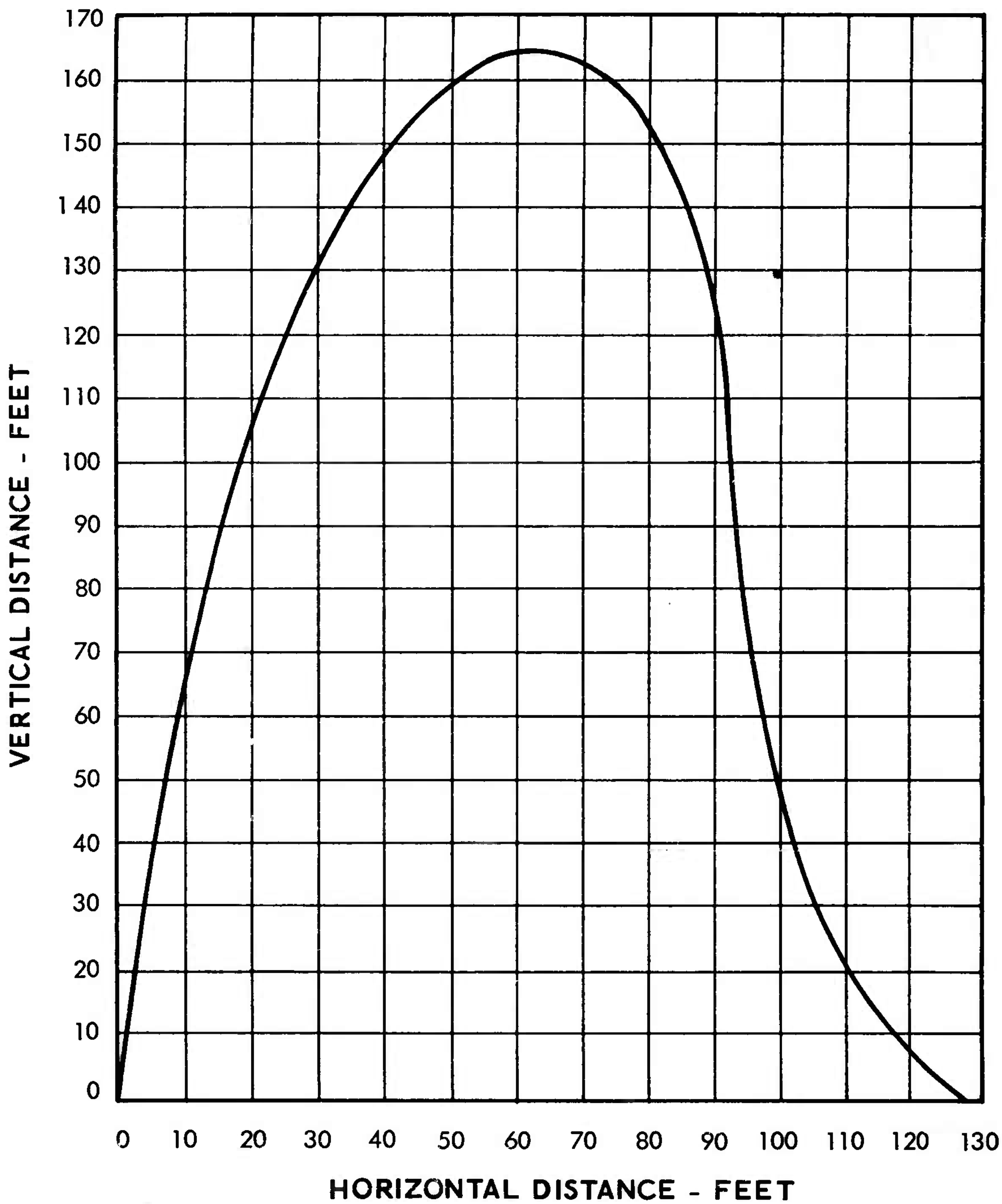

Figure 31. Trajectory - Test No. 4.

APPENDIX I

The following government-furnished equipment (GFE) was acquired and used in conducting four test firings at the North American Aviation, Inc., Columbus Division facility.

Item	Qty	Nomenclature
1	4	Catapult rocket (XM-13)
2	8	T31E2 Initiator
3	1	Pressure Transducer Range 0 - 2000 psi Serial No. 602793
4	1	Pressure Transducer Range 0 - 10,000 psi Serial No. 602775
5	2	Army normal issue flight gear excluding harness

APPENDIX II

WITNESSES

The following persons were present for one or all test firings at the North American Aviation, Inc., Columbus Division facility:

USABAAR, Ft. Rucker, Alabama

Col. J. F. Wells
Capt. F. Johnson

Frankford Arsenal, Philadelphia, Pa.

H. MacDonald
R. Bagwell

North American Aviation, Inc., Columbus Division

R. K. Gast
R. L. Carter
J. A. Moran
S. C. Zeller
D. W. Beem
B. C. Solomonides

APPENDIX III

QUALIFICATION OF BALLISTIC COMPONENTS FOR THE LW-1 ESCAPE SYSTEM

The following ballistic components are Contractor-furnished for the LW-1 Escape System.

Drogue Gun P/N OA-A21 (Ordnance Associates)

Drogue Gun Firing Mechanism P/N OA-A13 (Ordnance Associates) (Component of OA-A21)

Drogue Gun Cartridge P/N OA-A16-6C2 (Ordnance Associates)

Drogue gun P/N OA-A21 is a modification of drogue gun P/N OA-A2. The modifications consist of a change in the method of mounting the drogue gun body and an alteration of threads to accept a OA-A13 firing mechanism. These modifications have no effect upon drogue gun operation; therefore, qualification of P/N OA-A21 by similarity to P/N OA-A2, a unit qualified to Phase I and II of MIL-D-21625, is considered acceptable by this Contractor.

The drogue gun firing mechanism P/N A-A13 has been previously qualified as a part of Ordnance Associates gas generator P/N OA-A14. This gas generator was designed in accorance to North American Aviation Specification NA5-4517-3 and was qualified in accordance to MIL-D-21625. Bureau of Naval Weapons approval of this unit was received by BuWeps Letter RMMO-332/JGB dated 26 October 1960.

Ordnance Associates cartridge P/N OA-A16-6C2 is considered qualified due to similarity to P/N OA-A15-1.11A and OA-A15-1.46A cartridges used on the A3J Escape System. The difference between these cartridges is that OA-A16-6C2 is an instantaneous cartridge whereas P/N OA-A15-1.11A and OA-A15-1.46A function with a time delay. P/N OA-A16-6C2 is identical to a qualified cartridge P/N OA-A5-0 as to quantity and type of output charge. P/N OA-A15-1.11A, OA-A15-1.46A and OA-A5-0 have been qualified in accordance to MIL-D-21625. Bureau of Naval Weapons has granted service release on P/N OA-A5-0 by BuWeps Letter Aer-AE-5212/84 dated 1 June 1959, and P/N OA-A15-1.11A and P/N OA-A15-1.46A have been released by BuWeps Letter RMMO-332/JGB dated 26 October 1960.

The following ballistic units used on the LW-1 Escape System are GFE and no statement of qualification is required on these units:

XM-13 Catapult Rocket
T-30E1 Initiators

DISTRIBUTION

USCONARC	3
USAAVNBD	1
USATMC(FTZAT), ATO	1
NATC	2
CofT	8
USATMC	20
USATTC	4
USATSCH	3
USATRECOM	33
OUSARMA	1
TCLO, USAABELCTBD	1
USASRDL LO, USCONARC	2
USATRECOM LO, USARDG (EUR)	1
USAEWES	2
AFSC (SCS-3)	1
AFSC (Aero Sys Div)	2
CNO	1
CNR	3
BUWEPS, DN	5
CMC	1
USASGCA	1
Canadian LO, USATSCH	3
BRAS, DAQMG (Mov & Tn)	4
USASG, UK	1
Ames Rsch Cen, NASA	3
ASTIA	10
USAMRL	2
ASD, FCL	1
Experimental Track Branch, Edwards AFB	1
North American Aviation, Inc.	10

North American Aviation, Inc., Columbus Division, Columbus, Ohio, GROUND OPERATIONAL RECOVERY TESTS OF THE LW-1 EJECTION SEAT, Report No. NA60H-667, June 1962, TCREC Technical Rept 62-47, 43 pp. incl. illus. (Contract DA 44-177-TC-659) USATRECOM Task 9R38-01-017-61

Unclassified Report

Four static, ground operational recovery tests of the LW-1 catapult-rocket escape system were conducted from 28 September 1960 through 5 October 1960, at the Columbus Division of North

(over)

1. LW-1 Test Results
2. Ejection Seats-Recovery

North American Aviation, Inc., Columbus Division, Columbus, Ohio, GROUND OPERATIONAL RECOVERY TESTS OF THE LW-1 EJECTION SEAT, Report No. NA60H-667, June 1962, TCREC Technical Rept 62-47, 43 pp. incl. illus. (Contract DA 44-177-TC-659) USATRECOM Task 9R38-01-017-61

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North American Aviation, Inc., Columbus Division, Columbus, Ohio, GROUND OPERATIONAL RECOVERY TESTS OF THE LW-1 EJECTION SEAT, Report No. NA60H-667, June 1962, TCREC Technical Rept 62-47, 43 pp. incl. illus. (Contract DA 44-177-TC-659) USATRECOM Task 9R38-01-017-61

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